Colonia 3D

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Abstract

Virtual 3D reconstructions of archaeological excavation sites, artifacts, and architecture play an important role preserving our cultural heritage for future generations. The communication of cultural heritage in public spaces, e.g. museums or exhibitions, is commonly used for purposes of study, education and enjoyment. Here, virtual reality offers new communication channels, whose use in public spaces statically increased over the last years. Used in combination with interactive visualization technology, they become a powerful tool to support scientific discussions among experts and to present important archaeological facts to broad audiences using museum and edutainment applications.

1 Introduction

As an interdisciplinary team, consisting of archaeologists, designers, and computer graphic engineers, the project "Visualization of Roman Cologne" started with the aim to reconstruct high-detail virtual 3D models and create a visualization framework that enables the interactive exploration and presentation of a virtual reconstruction (Figure 1). This paper presents the results of the combined expertise of all teams. It can be read as a guideline for similar future projects, e.g., to setup a collaborative content creation process, select appropriate data exchange formats, or to apply the presented visualization and optimization techniques to other domains of virtual archeology.

With the beginning of the digital revolution in the second half of the 20th century, a new era heralded for all information-related activities, redefining how information is retrieved in economic, social and technological systems today. The communication of cultural heritage is one of these areas that experienced a continuous growth during this time, where it leveraged from the digitalization for a long-ranging preservation and efficient communication of context-sensitive information.

Fig. 1: Overview of the complete 3D reconstruction of Colonia3D.

With major interest, the reconstruction of archaeological excavation sites emerged as a powerful tool to communicate archaeological features and cultural knowledge, not only to experts, but also to broad audiences of exhibitions or museums. A continuation of this trend for these public spaces involves digitized cultural heritage, in order to enable people an immersive exploration of collections for inspiration, learning and enjoyment. With the ongoing advancements on the field of virtual reality over the last years, the coupling with digital cultural heritage has evolved as a promising application for an effective and immersive communication of this context-sensitive information. Here, the visualization with interactive 3D applications opens a new degree of freedom beyond the mere presentation of static visualizations. They enable a user to directly interact with 3D virtual environments and support the depiction and exploration of digital cultural heritage artifacts in real-time.

However, these scenarios mostly induce highly complex and massive data, as being true to the original is one of the goals. Consequently, visualization concepts and strategies are required that do not only permit an effective communication of information, but also guide a user throughout these scenarios, since varying levels of experiences within interactive media can be assumed. Therefore, visualization techniques are required on both, technical level in order to enable a real-time visualization of the reconstructions, and conceptual level for facilitate users to interactively explore the environment and perceive this information intuitively.

In this paper we present general concepts and implementations of visualization techniques for interactive 3D reconstructions of digital cultural heritage in public spaces, by example of the project Roman Cologne. In particular, this paper makes the following contributions to the community: (1) it presents a concept for the communication of digital cultural heritage in public spaces, such as museums or exhibitions. (2) it describes research results for a prototypical application and implementation of a client-server model for information communication and human computer interaction in public spaces.

2 3D Virtual Environments for Digital Cultural Heritage

Numerous projects involve the modeling and rendering of digital cultural heritage in 3D virtual environments. Remondino et al. present the 3D-Arch project captures and model complete geometric and colour details on exterior and interior of castles in Trentino province (northern Italy) for accurate documentation and photo-realistic visualization [Remo09]. Papagiannakis et al. present a 3D reconstruction of ancient fresco paintings for a revival of life in ancient Pompeii, that manage to simulate virtual characters in real-time using augmented reality [Papa05]. Song et al. focused on the Singapore region and a reconstruction of Peranakans and their culture using virtual reality [Song 03]. Laycock et al. illustrate four-dimensional data and visualize different time periods of the reconstruction of the city of Koblenz (Germany) [Layc08]. Here, architectural styles of buildings, building heights and roof styles are altered over time in order to facilitate a case study for a 4D navigable movie.

The project Virtual Reality Notre Dame (VRND), DeLeon and Berry build on a gaming-based 3D engine in order to facilitate a virtual tour guide with high-resolution imagery at real-time rates [DeLe00]. With respect to the VRND project, Papagiannakis et al. describe methodologies how to use widely available standard programming languages and APIs (application programming interface) so as to not base on proprietary commercial 3D game engines, but still achieving visually compelling results [Papa01]. Kuchar et al. presented a photorealistic real-time visualization of Friedrichsburg Castle (Germany) [Kuch07]. The project relies on the RadioLab system for performing radiosity lighting using high dynamic range (HDR) daylight simulation. Magnenat-Thalmann et al. proposed 3D real-time virtual simulations of the populated ancient sites of Aspendos and Pompeii, where they facilitate from virtual reality and simulated dynamic virtual humans for an immersive experience [Magn06].

In 1994, a first application using virtual reality for heritage has been presented, that allowed the audience to interactively explore a 3D reconstruction of Dudley Castle (England) on a regular screen [Bola96]. More sophisticated installations made use of the CAVE system, where the illusion of immersion is sustained by the projection of visuals on display screens of a cube and the audience positioned in the middle [Cruz93]. Examples are the Dunhuang caves by Lutz and Weintke [Lutz99] and a reconstruction of an ancient greek temple in Messene by Christou et al. [Chri06]. A third installation possibility targets on panoramic screens of cylindrical shape. Carrozzino et al., for example, used in the Virtual Sculpture Museum of Pietrasanta (Italy) a panoramic stereo screen of cylindrical shape for raising the level of immersion [Carr08].

3 3D Reconstruction and Visualization

To start the collaborative work, we first setup a content creation pipeline, define the data exchange formats, possible use-cases, and the roles for each team. This process should guarantee that all experts within the teams can operate in their domains without restrictions. Additionally, the pipeline is designed to facilitate three important aspects: **Content preservation:** The representation and encoding formats of the accumulated primary (3D models) and secondary data (multimedia content) has to ensure its accessibility for future usage. **Extensibility:** The established pipeline should support the integration of upcoming ideas and new technology in all its stages during the project. **Re-usability:** The developed framework should be robust, flexible, and easily adaptable to enable its application in other interdisciplinary visualization projects.

1.1 Scientific Reconstruction

To create a complete 3D model representing the ancient town of Cologne, a number of single roman structures and building elements have to be reconstructed first. The reconstruction of these elements, their combination, and arrangement was done by the archeology experts. For this task, known facts from previous research, results of actual publications, as well as recent finds of the local department of antiquities of the Romano-Germanic Museum Cologne were considered. Only well-studied buildings, with a scientifically evaluated shape or floor plan, were reconstructed in high detail. For all other elements only simple shapes were selected for the reconstructions to communicate the missing evidence. Additionally, a digital terrain model (DTM) of the ancient Cologne with building sites and streets was reconstructed. It was derived from a DTM of the present Cologne, whose geo-reference was adapted to the location of finds as well as to known morphological changes in the past.

The reconstruction results represent the scientific fundament and are used by the design team to create the virtual 3D models. Therefore, archaeologists deliver all suitable data, such as textual descriptions, photographs of artifacts, and highly detailed 2D computer aided design (CAD) drawings of building parts and their arrangement to the designers.

1.2 3D Model Creation

Based on this scientific evaluated material, designers create virtual 3D building models for the real-time visualization and secondary content for the presentation of additional information. The major challenge for designers is to balance the trade-off between visual quality and suitability for real-time rendering. On one hand, archaeologists demand for maximum visual quality for every detail. On the other hand, computer graphic engineers rely on low polygonal representations for fast rendering on graphics hardware, to ensure interactivity for the expected number of high-detail building models. Generally, all individual objects are constructed with the least possible amount of polygons while remaining the original shape.

After a library of 3D elements (e.g., capitals, columns, and doors) was created, these structures are combined to complete buildings and provided with 2D texture-maps representing the respective materials. These material textures are based on color templates prepared by the archaeologists. Further, static lighting conditions are assumed to enhance the 3D impression of the models and to accelerate rendering. Therefore, the material textures are combined with light maps, which are derived from global illumination simulations.

To exchange 3D models a data format has to be selected that meet the following three criteria: (1) It has to be supported by digital content creation (DCC) tools used by the designers (Cinema4D, 3DSMax); (2) To provide content preservation, the format should be extensible, future proof, and store information lossless; (3) The format should support a minimum set of standard features (e.g., geometric transformations, color and material definitions, geometry instancing, and external references for reusing building elements. We decided to use the Collada exchange format. It fits all of above requirements, is based on an XML scheme, has an open specification, and is supported by a large number of major 3D hardware and software companies.

1.3 Interactive 3D Visualization

Compared to static 2D illustrations, interactive 3D visualizations, presenting the Roman buildings within their context, enable archaeologists to discuss or validate their hypotheses with a direct access to the spatial situation. Thus, it become possible to analyze the arrangement of buildings related to the terrain, their mutual visibility from a pedestrian perspective, or the connectivity regarding to the path network. To support these tasks in virtual archeology applications, two conditions have to be considered: (1) users demand for free navigation, to enable them to inspect every detail in the complete 3D scene. They do not accept restrictions to particular areas or viewing angles; (2) the models delivered to the 3D CG engineers are created with standard DCC tools.

For these reasons, and because Collada is more a flexible exchange format than an efficient storage or rendering format, the 3D models have to be converted in a first step. Therefore, we developed a configurable converter tool chain that applies a set of optimizations to each model to prepare it for efficient real-time rendering. To minimize the loading times this converter uses a simple binary format for persistent storage of the optimized 3D model representations. Nevertheless, the Collada representations are not affected and stay preserved as input data for other visualization applications in the future.

To improve the rendering performance for a scene constructed out of a number of individual 3D models, a further set of optimizations is applied. Because illumination was pre-computed for static lighting and stored combined with material colors in the surface textures, lighting computations are turned off during interactive rendering. Besides model optimization, the second task of the CG team is to develop an application framework for the interactive presentation, analysis, and exploration of the models. To support the need of different end-user groups, this team is responsible for permanent framework extension with enhanced visualization and adaptive navigation techniques.

4 Exhibition Concept

The main requirements for the exhibition located at the Roman Germanic Museum (RGM) comprised the interactive exploration, the display of additional information as well as a guided interaction with the virtual 3D reconstruction. It mainly consists of the following two components: (1) a rendering server performs real-time image synthesis of the 3D scene; (2) a client offers user control for the servers viewing configuration (e.g., the presentation modes) via a touch-based user interface and a 3D mouse. It displays additional information about the scene projected and is adapted to the presentation modes respectively.

1.4 Client/Server Approach

The client-server approach has two major advantages for systems that provide interactive installations within public places: (1) multiple viewports provides more physical space to display information; (2) it enables guided interaction and navigation with the 3D virtual environment using 2D touch events and an additional 3D mouse to control the virtual camera.
The communication between the client and the server is implemented using a simple text-based protocol, which can be easily extended and maintained. The textual messages are exchanged via TCP/IP sockets, whereas the client controls state consistency and initiates hand-shakes and synchronization.

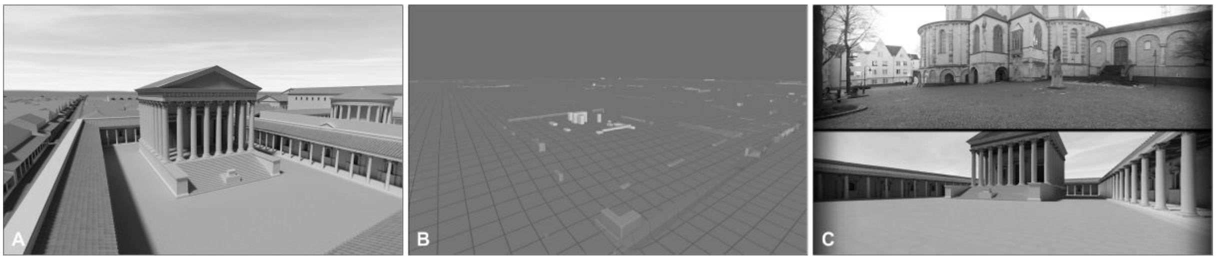

Fig. 2: Visualization modes of Colonia3D: reconstruction mode (A), findings mode (B), and comparison mode (C).

1.5 Visualization Modes

This section describes the different presentation modes provided for the effective communication of 3D digital cultural heritage in interactive 3D virtual environments. Figure 2 exemplifies the visualization of the following three modes: the *reconstruction*, *comparison*, and *findings* mode.

1.5.1 Reconstruction Mode

The visualization of possible virtual reconstructions or artifacts can be considered as main purpose for a system that communicates digital cultural heritage. It forms the basis for the remaining two presentation modes. Such reconstruction visualization is the result of numerous projects that deal with interactive 3D virtual environments. Figure 2 (A) shows such visualization by the example of Roman Cologne. Basically, there are two possibilities for the images synthesis of this visualization mode: photo-realism vs. abstract visualization. For example, in the case of Roman Cologne people often wish to have more realism in texturing and lighting, but archaeologist concerns that this would imply a "finished" reconstruction to the user. We choose an abstract, non-photorealistic, and simple coloring schema to communicate that the visualized reconstruction is only one out of many realities.

1.5.2 Comparison Mode

Based on the reconstruction mode, the comparison mode enables the comparison and dissemination of structural changes over time, i.e., between the reconstruction and today's state. We further observed, that this mode enable visitors with a local background a certain degree of entertainment. For the visualization framework of Roman Cologne, we apply a simple image-based approach that allows the side-by-side comparison of locations between the modern Cologne and the ancient version (Figure 2 (C)). Instead of planar images, we create 360° horizontal panoramic images which are mapped onto two cylinders, each rendered using a virtual camera with an orthographic projection. To navigate within this setup, the user can rotate both panoramic cameras at the same time.

The images required for the comparison mode are obtained by photographs and application screen shoots. In the case of Roman Cologne, we use panoramic images with 360 degrees horizontal field-of-view. After relevant positions are determined within the reconstruction, a photographer acquired real-world images, which are aligned and stitched. The 3D visualization framework can acquire panoramic images using a rendering technique described in [Trap08].

1.5.3 Findings Mode

The purpose of this mode is the communication of the findings at their respective locations, which represent the basis for the actual reconstructions. Our goal was to enable a user to understand the relation between artifact and proposed 3D reconstructions performed by archaeologists and designers. As an example, Figure 2 (B) shows screenshots for the reconstruction mode of the main temple within Roman Cologne. Approaches for the communication of finding information embedded in reconstruction visualizations have to deal with the following challenges: (1) multiple findings for a single reconstruction require interaction concepts and rendering techniques for the selection and highlighting of an instance or a group of finding objects; (2) the approaches require a concept that enables the communication of different reconstructions that can be derived from a set of findings; (3) it is necessary to handle different graphical representations for a finding object: 2D photographs, hand-drawn or digital images, as well as 3D polygonal meshes or point clouds, which are obtained from laser scanning; (4) textual descriptions are likely the medium that conveys and communicates the most context information. However, the depiction of text is limited by the available screen space and rendering quality.

The system supports the visualization of different 3D reconstructions for a single set of findings. These versions can be mutually blended with the rendering of the highlighted findings. The user can control the blending factor as well as the blending speed.

1.6 Interaction Concept

This section focuses on the user interface of the client and the control of server's virtual camera. As a basic functionality, the touch interface enables switching between the three proposed presentation modes. The avoidance of "getting lost situations" [Buch05] in 3D virtual environments is one of the major goals of the proposed interaction and navigation metaphors. This comprises a trade-off between navigation aids or constraints and the unconstraint freedom to interact with the system.

An overview map facilitates the orientation of the user. It contains a camera glyph indicating the position and orientation of the virtual camera within the 3D scene. To ease the access to specific locations in the 3D virtual reconstruction, the touch interface presents a number of hot spots, which can be selected from a scroll menu at the bottom. After selecting a hot spot the server's virtual camera automatically approaches it by using automatic camera control, which is an important feature for interaction within 3D virtual environments. It is applied for moving the 3D virtual camera between hot spots and between different findings in the scene. Instead of explicitly modeling more than 100 camera paths we decided to derive these paths automatically. Given the start and target camera settings, and the path duration, our system creates the camera path in the following manner: (1) to avoid possible collisions with buildings, the camera positions are interpolated on a parabolic path; (2) the viewing directions of the virtual camera are interpolated linearly; (3) non-linear speed is used, which results in a slow path start and end.

With respect to the interaction possibilities, we distinguish between two basic types of hot spots: an overview hot spot and local hot spots. The local one enables user interaction using an orbital camera model only, while the global hot spot enables unconstraint navigation using a 3D mouse. If in comparison mode, the 3D mouse rotates the panorama visualization. In addition thereto, the rotation can be controlled via a slider on the touch interface. In the findings mode, a flow-menu is presented from which particular finding can be selected. Successively, the server moves the camera closer to the finding and highlights it. A slider can be used to fade-in the available reconstructions for the respective hot spot.

5 Conclusions

This paper presents the results of the project Colonia3D. It describes the process of creating interactive 3D virtual reconstructions, considering an interdisciplinary team of archaeologists, designer, and computer scientists. It further presents three different presentation modes for the effective communication of digital cultural heritage in public space, such as exhibitions or museums. We further describe interaction concepts, based on a client-server framework that is especially suitable to navigate 3D virtual environments within public spaces.

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